Self Motion and the Vestibular Foundations of Spatial Cognition: Neurophysiological and Computational Mechanisms

ONR Grant # N00014-94-1-0154

B.L. McNaughton, Ph.D., P.I.

Summary of Progress for 1993-94

The overall specific aim of the project is to understand the biological basis of how information derived from the body's motion in space interacts with information about visual landmarks, to generate a high level spatial reference framework in the mammalian CNS. A better understanding of these higher level systems for spatial orientation will ultimately aid in the development of technologies for the prevention of spatial disorientation related aviation accidents.

The funded proposal consists of 3 main experiments, all of which employ a new, advanced technology for parallel neuronal signal acquisition that was developed by the P.I. under prior ONR support. The first experiment involves an analysis of how large populations of hippocampal neurons, that are known to code for spatial location, individually encode specific landmarks or events of task relevance to the organism. The second experiment seeks to understand how trajectories to spatial targets might be planned by means of a vector subtraction operation. Specifically, it involves the question of whether impending spatial goals are transiently represented in the hippocampus, prior to the initiation of movement to them. This would enable an appropriately configured neural network to perform a subtraction of a stored landmark vector from the currently perceived one. Finally, the third experiment attempts to find evidence for landmark distance encoding cells. Such cells would complement the known population of head-direction (bearing) cells, and provide the other, as yet missing, component from which the hypothetical landmark-vector cells in hippocampus are presumably derived.

In the past year, we have made substantial progress on experiment 1, developed a behavioral task appropriate to experiment 2 and obtained some preliminary data in favor of its background hypothesis. For experiment 1, we have conducted parallel recordings of hippocampal neurons (463 total) in a modified version of the Collett Landmark Task essentially as described in the proposal (see abstract by Gothard et al.). We found clear evidence for different neurons in hippocampus encoding for specific objects (landmarks) that were placed in variable locations with

respect to a fixed spatial reference framework. These findings, which confirm the hypothesis that at least some hippocampal cells specifically encode the animal's spatial relationship to particular objects, are being prepared for publication.

For experiment 2, we have begun with a somewhat simpler version of the task that was initially proposed in order to improve the statistical sampling of the data and to speed up the learning by the rat of the required task. The modified task involves what is essentially a rectangular, squashed, figure-8. The rat's task is simply to run down the central alley way and go alternately to the left or right corners for food reinforcement. We look for place cells with fields at or near the choice point or near one of the goals. The hypothesis is that there will be transient activity near the choice point of cells representing the goal locations, and/or that cells representing the choice point will be transiently suppressed or show differential activity depending on which direction of turn is to be made. We have so far collected a fairly large amount of data on this task from two rats. The data are not yet analyzed; however, observations made during the recording sessions suggest that at least one case of modulation of activity depending on the goal was observed.

In the next year of support, we will complete and publish the landmark representation studies of experiment 1. Specifically we still need to collect data showing whether the cells representing relationships to different landmarks fire simultaneously or asynchronously if the landmarks are positioned so that the firing fields of the two classes of cells overlap. This question is crucial to an interpretation of the computational significance of the phenomenon. We will also collect and analyze most or all of the data necessary to answer the questions posed in experiment 2.

Manuscripts published or in press and meeting abstracts:

Wilson, M.A. and McNaughton, B.L. Reactivation of hippocampal ensemble memories during sleep. Science, 265, 676-679, 1994

McNaughton, B.L. Knierim, J.J. and Wilson, M.A. Vector encoding and the vestibular foundations of spatial cognition: Neurophysiological and computational mechanisms. In: The Cognitive Neurosciences , Gazzaniga, M.S., (ed.). MIT Press, pp. 585-595, 1994.

McNaughton, B. L., Shen, J., Rao, G., Foster, T. C., and Barnes, C. A. Persistent increase of hippocampal presynaptic axon excitability after repetitive electrical stimulation: Dependence on N-methyl-D-aspartate receptor activity, nitric-oxide synthase, and temperature. Proceedings of the National Academy of Sciences, U.S.A., 91, 4830-4834, 1994.

Barnes, C. A., McNaughton, B. L., Bredt, D. S., Ferris, C. D., and Snyder, S. H. Nitric oxide synthase inhibition in vivo: Lack of effect on hippocampal synaptic enhancement or spatial memory. In: Long-Term Potentiation, Vol. 2 (M. Baudry and J. L. Davis, eds.). MIT Press, pp. 37-43, 1994.

Knierim, J.J., Kudrimoti, and McNaughton, B.L. Hippocampal Place fields, the internal compass, and the learning of landmark stability. J. Neuroscience, 1995, in press.

Skaggs, W.E., Knierim, J.J., Kudrimoti, H.S. and McNaughton, B.L. A model of the Neural Basis of the Rat's Sense of Direction. Advances in Neural Information Processing Systems, 1995, in press.

Gothard, K.M., Skaggs, W.E., Moore, K.M., and McNaughton, B.L. Behavioral correlates of hippocampal CA1 cells in a landmark navigation task. Society for Neuroscience Meeting, Miami, FL, November 1994 (Abstract)

Knierim, J.J., Kudrimoti, H.S., and McNaughton, B.L. Dynamics of visual cue control over head direction cells and place cells. Society for Neuroscience Meeting, Miami, FL, November 1994 (Abstract)

Qin, Y., Markus, E.J., McNaughton, B.L. and Barnes, C.A. Hippocampal place fields change with navigational context. Society for Neuroscience Meeting, Miami, FL, November 1994 (Abstract)